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(54) Title: WHITE LIGHT SOURCE

(57) Abstract: White light source is proposed that includes light-emitting diode and phosphor transformer. The diode emits blue light that is applied to the transformer implemented as columnar-shaped single-crystalline phosphor. Part of the light, more than half in quantums, being mixed, is transformed here into yellow quantums. The both parts, being mixed together, give white light. Owing to the columnar structure of the transformer, the white light has a directional nature. This expands the spectrum of applications of the white light sources.

WHITE LIGHT SOURCE

FIELD OF THE INVENTION

This invention relates to light engineering, microelectronic components, and electron materials science.

BACKGROUND OF THE INVENTION

White sources are known, for example, as luminescent lamps where radiation excited by low-pressure gaseous discharge of mercury vapors is transformed into visible ("white") light by phosphor [1]. However, the luminescent lamps have some serious drawbacks:

(a) the mercury vapors are ecologically unacceptable: both at destroying of the lamps and during their production;

(b) efficiency of the lamps (about 12 lm/W), although higher than that of incandescent lamp (about 5 lm/W), is still rather low.

White light sources are known as solid-state semiconductor light emited diodes (LED) based on gallium nitride and related compounds [2]. In such devices, short-wave (blue) light emitted by the diode is partially transformed by a phosphor into longer-wave (for example, yellow) light and then, being mixed with the initial blue light, gives the white radiation.

The efficiency of such light sources depends strongly on the efficiency of transformation of the phosphor. Standard phosphors are formed by a set of fine (micron- and submicron) crystalline grains of approximately isometric forms arranged chaotically one on another (Fig. 1). In particular, fine-crystalline $Y_3Al_3Ga_2O_{12}:Ce$ phosphor is used in [2]. The phosphor is distributed in an organic binder. Such a phosphor absorbs the initial blue radiation of the LED and emits yellow light with wave-length 565 nanometers. By mixing the two radiations, white radiation is formed.

However, at propagation of the light, both the initial and exited ones, through the phosphor, it is scattered by the grains and partially lost. As a result, efficiency of the light transformation is decreased, sometimes significantly.

One more drawback of the transformation used in [2] is the fact that, due to a low thermal conductivity of the organic binder, the phosphor is superheated and, on this reason, deteriorates.

These drawbacks are eliminated in the our invention.

SUMMARY OF THE INVENTION

A white light source is proposed that includes light emitting diode and phosphor transformer. The transformer is implemented as single-crystalline phosphor columns arranged on a transparent substrate. The columns are mutually parallel, forms angles 10° to 90° with the substrate, have cross-sections of various shapes. Heights of the columns exceed their diameter. Gaps exist between the columns, the gaps being filled by high-refractive material. The light-emitting diode emits light in the range 440-480 nanometers with the absorption coefficient more than 10^6 m^{-1}, whereas the transformer emits light with the wave-length in the range 560-590 nanometers at the ratio of yellow-light power, generated by the transformer, to the blue-light power conserved after passing the columns, more than 2:1. The transformer is placed on the output surface of the light-emitting diode being connected with it via an immersion medium that has a refraction coefficient lower than the refraction coefficient of the phosphor.

The ratio of the height of the columns to their diameter is not less than 2.

The transformer can be faced to the surface of the light-emitting diode by either its substrate or by the columns.

The volume of the columns takes more than 90% of the transformer.

BRIEF DESCRIPTION OF DRAWINGES

Fig. 1. A scheme of the standard phosphor consisting of approximately isometric crystalline grains: 1 – light or electron beam; 2 – transparent substrate.

Fig. 2. A scheme for propagation of light in columnar crystals: 1 – light or electron beam; 2 – transparent substrate.

Fig. 3. A scheme of white light source that contains a light-emitting diode, a phosphor transformer, and an immersion connecting layer: 1 – the light-emitting diode; 2 – the immersion layer; 3 – a transparent substrate; 4 – luminescent (phosphor) columns; 5 – gaps between the columns filled with a low-melting-point light-absorbing material.

Fig. 4. Two versions of the transformer arrangement: a – by the columns faced to the light-emitting diode; b – by the substrate faced to the light-emitting diode.

BEST VERSION FOR REALIZATION OF THE INVENTION

In the light source proposed, the light is channeled by passing it through elongated phosphor crystalline grains. This is implemented with using phosphor having columnar structure proposed in [3]. In such phosphors, the light propagates along the columns reflecting from their walls according to the full internal reflection Fig. 2). Typically, it is undergoing only a small losses.

In addition, the columnar phosphors contain no organic binder.

A scheme of the proposed white light source is depicted in Fig. 3. An immersion layer is placed between the light source and the transformer. The layer can contain various transparent substances such as silicones, polymers, epoxies, low-melting point eutectics such as $KCl+NaCl+LiCl+MgCl_2$ etc.

The light from the light-emitting diode arrives through the immersion layer to butt-ends of the columns. When the blue light propagates along the columns, it is transformed into yellow light that is a "complementary" to the blue one.

Thus, in accordance with the current invention, phosphor columns are created that are able a part of the blue light arriving from the light-emitting diode to transform into yellow light. In order to ensure formation of the white light, the ratio of the formed yellow light to the remaining part of the blue light (after passing the columns) should be (in power or, better, in the number of quantums) about or slightly more than 2:1.

Phosphor columns are formed of light-conductive thermal-conductive inorganic material. They are attached to an inorganic (glass) substrate by a large contact area. The good thermal conductivity provides an advantage to the phosphor transformer and, in such a way, to all the light source. This advantage is ensured also by the fact that total volume of the columns takes more than 90% of the transformer. Remaining part of the phosphor, namely gaps between the columns, are filled with electroconductive (accordingly, good-thermal-conductive) high-refractive material.

Good light-engineering parameters of the white light source are ensured by the fact that it is characterized by a good spectral matching between the wavelength of the light-emitting diode (450-480 nm) and the maximum exciting spectrum of the phosphor transformer used (440-475 nm). High absorption coefficient of the phosphor

used ($10^6 - 5.10^6$ m^{-1}) allows to reach a high (more than 50-60%) level absorption of gallium nitride light-emitting diode even at a small (about several micrometers) height of the phosphor columns. At the quantum yield of the photoluminescence about 1, the yellow light formed contains about 70% quantums; together with 30% remaining quantums of the blue light bright white light is generated.

EXAMPLE

The columnar phosphor is produced of a solid solution of ZnS:CdS having the proportion 70:30 to 50:50 doped with copper at concentration 1.10^{-3} to 1.10^{-2} gram/gram (gram Cu/gram ZnS+CdS). The columnar phosphor is prepared by vapor deposition according to the patent application [3].

After the deposition of the columnar phosphor the structure obtained is filled by a high-refractive low-melting-point material, such as Bi_2O_3-B_2O_3, is ground and polished.

The white light sources have numerous applications:

- light sources of domestic and industrial applications;
- traffic lights;
- lighting scales;
- point static and dynamic indicators with running line;
- multielement situation screens;
- others.

REFERENCES

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2. R.Dixon, Who's Who in Blue and Green LEDs, Compound Semiconductor **5** (1999) #5, pp. 15-19.
3. E.I.Givargizov, L.A.Zadorozhnaya, A.N.Stepanova, N.P.Soshchin, N.N.Chubun, and M.E.Givargizov, Cathodoluminescent Screen with a Columnar Structure, and the Method for its Preparation, WO 99/22394 (1999).

CLAIMS

1. White light source including light emitting diode and phosphor transformer **wherein** the transformer is implemented by single-crystalline phosphor columns arranged on a transparent substrate, the columns have are mutually parallel, forms angles 10° to 90° with the substrate, have cross-sections of various shapes, preferentially isometric ones, heights of the columns exceed their diameter, gaps exist between the columns, the gaps being filled by high-refractive material, the light-emitting diode emits light in the range 440-480 nanometers with the absorption coefficient more than 10^5 m^{-1}, the transformer emits light with the wave-length in the range 560-590 nanometers at the ratio of yellow-light power, generated by the transformer, to the blue-light power conserved after passing the columns, more than 2:1, the transformer is placed on the output surface of the light-emitting diode being connected with it via an immersion medium that has a refraction coefficient lower than the refraction coefficient of the phosphor.

2. The white light source according to the point 1 **wherein** the ratio of the height of the columns to their diameter is not less than 2.

3. The white light source according to the point 2 **wherein** the transformer is faced to the surface of the light-emitting diode by its substrate.

4. The white light source according to the point 2 **wherein** the transformer is faced to the surface of the light-emitting diode by the columns.

5. The white light source according to the point 1 **wherein** the volume of the columns takes more than 90% of the transformer.

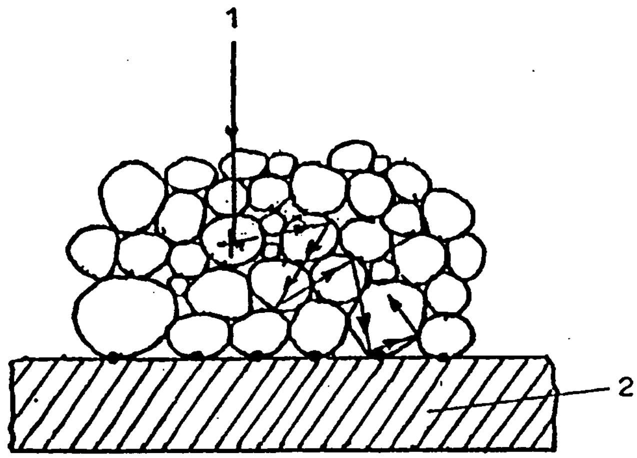

Fig. 1.

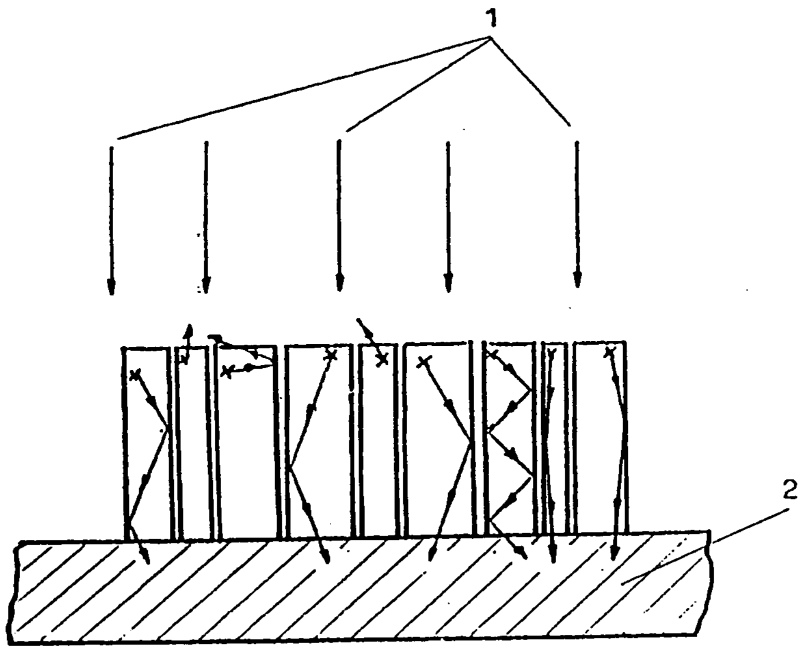

Fig. 2.

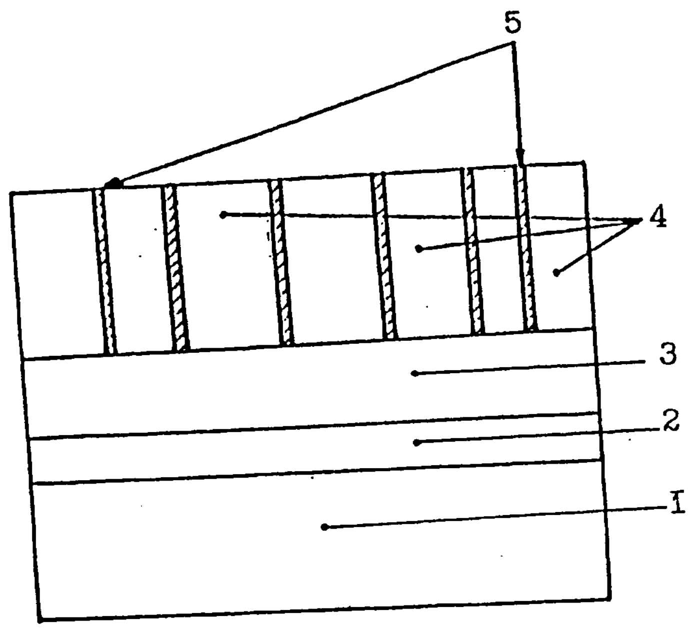

Fig. 3

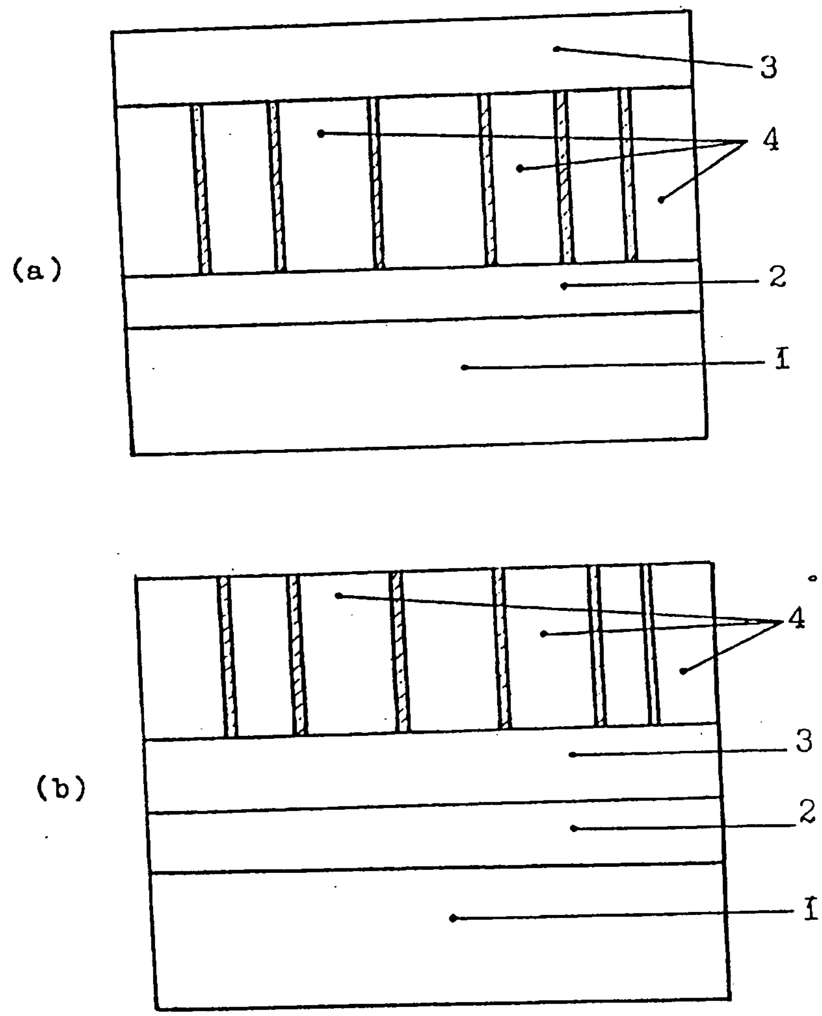

Fig. 4.